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"Nuclear Energy - Potential to Substantially Impact California's Energy Use"

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"Nuclear energy -- potential to substantially impact California's energy usage"

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A. Short overview of the main issues facing nuclear power's future expansion

The use of nuclear power to generate electricity is very widespread today, with about 20% of all U.S. electricity coming from the nation's 103 operating reactors. Worldwide there are over 400 commercial nuclear plants that make a similar contribution percentage-wise. However, all of the current U.S. reactors and most of those elsewhere are relatively old, with no new ones having been started domestically in over two decades and only a few now being built overseas, mostly in Asia. The principal reason for this hiatus in the U.S. is that the cost of electricity from new nuclear plants has been non-competitive with other electricity sources for a long time.

The U.S. nuclear-power industry has not been stagnant during this time, however. First, the existing plants themselves are running significantly better than they were twenty years ago, to the extent that the US. reactor fleet is producing about one-third more electricity annually than it was, due largely to improvements in the capacity factors: the plants run more reliably, shut down less often, and the refueling outages take less than half as long as they once did. The safety performance has also improved dramatically, with major improvements in every one of the main indicators of safety. The security of the plants against sabotage or other malevolent acts has always been very strong, and is stronger still after recent upgrades in response to the September 2001 attacks in New York and Washington. Thus the U.S. nuclear-electricity industry has remained dynamic despite the absence of new construction.

The U.S. and foreign companies that design reactors and hope someday to sell more of them have also been actively at work -- they have developed advanced reactor designs that promise to cost much less to build and to operate, and to have even better safety performance. Several of these advanced designs have received design-certification approvals from the U.S. Nuclear Regulatory Commission, meaning that a utility could order one of these certified designs today with confidence that the NRC approval of that design is already in place. These new reactor designs are advanced versions of the existing reactors: broadly similar in their design concept but incorporating important new safety and reliability features and cost-saving features. The term "evolutionary" is used to describe these designs, in contrast to several advanced reactor designs whose engineering concepts are very different.

Today, for the first time since the long hiatus began in the U.S. in the late 1970s, a resurgence of interest in ordering new reactor plants has occurred among the electric utilities. Several utility companies or utility consortia have announced tentative plans to build new reactors using one of the "evolutionary" new designs. Also, several sites have been tentatively selected for the new reactors, and these sites are now being examined by the NRC for possible approval. Finally, recent Congressional legislation (the Energy Policy Act of 2005) provides financial incentives and subsidies for the first several new reactors as a means of stimulating the first few new orders.

Meanwhile, progress to resolve the high-level radioactive-waste issue continues, although its pace is much slower than had been predicted a decade ago. The Federal Government has been working for almost two decades to develop a deep-geological repository for disposing permanently of the reactor waste (spent fuel), at Yucca Mountain in remote southwestern Nevada. The design of the repository has been completed and is very advanced technically, and it seems likely to meet all applicable NRC regulations. However, the project's Congressional funding has recently fallen far short of what would be necessary to complete the repository soon. Current projections indicate that it might open, at the earliest, in the middle of the 2010-2020 decade.

Security and proliferation have been concerns from the start. Plutonium and highly-enriched uranium are the raw materials of nuclear weapons. Because reactors generate plutonium in their cores that could be extracted chemically, and because the front-end enrichment of uranium for reactor fuel is a technology that can also be used for making bomb-grade uranium, there has always been a concern that commercial nuclear-power technology could be adapted by a country (or perhaps even by a subnational group) for nuclear-weapons production. Added to this concern is the question about whether a terrorist group could attack a reactor and cause havoc, even including a large radiation release. These latter concerns have been amplified of course, since the September 2001 terrorist attacks in New York and Washington. The general consensus is that current U.S. reactors are very robust against such attacks, and in fact the current U.S. commercial "fuel cycle", in which no spent fuel is reprocessed, is generally also considered to be very robust against proliferation. This is true of nuclear-power systems like ours even if deployed in less trustworthy countries -- it is simply very difficult to use a reactor system like ours for military purposes. However, reprocessing technology (now practiced in a few advanced countries overseas) could, in the wrong hands, be used without too much difficulty to make plutonium for a weapon, and uranium-enrichment technology in the wrong hands could also be so used.

This has led to a concern that if nuclear power expands rapidly into countries that are less trustworthy, the possible proliferation from these facilities may represent a major national-security threat for the U.S. as well as for other advanced countries. This concern places a special burden on any advanced nuclear-power system, a burden to ensure that the technologies under development will embody very robust intrinsic security features that can make proliferation more difficult, not less, if they are widely deployed around the world.

This concern has led some to propose that the next round of expansion of nuclear power around the world be restricted to technologies similar to those now in use in the U.S. and in most other countries. However, for several reasons the current "evolutionary" reactor designs are far from optimal if nuclear power is to play a major and expanded role in worldwide electricity production over the long haul (over the full next century, for example). Fortunately, advanced design ideas exist for reactors and their supporting fuel cycle facilities that are significantly better in many ways, and ultimately, the world will need to deploy these advanced technologies if nuclear power is to play the major role that it is capable of. If the new ideas can be proven in practice, these advanced designs will be even safer, will cost much less to build and operate, will use much less uranium ore, will be even more secure against malevolent acts, and will produce far less radioactive waste (less quantities of it, and with less long-lasting dangers). Although the advanced reactor-and-fuel-cycle systems have been thought about for a long time, and although significant experimental work has been accomplished at smaller scales, first-of-a-kind demonstration units need to be built and operated before their expected benefits will be accepted. For advanced reactor technology, this is the major challenge today.

If nuclear power is to be a successful technology in the future in the U.S., the domestic U.S. nuclear industry (and the supporting government laboratories and university researchers) faces five separate challenges:

O First, the U.S. must continue to operate the existing fleet of over 100 reactors safely, securely, and economically over their remaining lifetimes.

O Second the U.S. must begin soon to build new reactors using the "evolutionary" designs, so as to expand nuclear energy's role soon (within the next decade or so),which is sooner than any more advanced design will be ready for deployment.

O Third, the country must begin working to develop the more advanced reactor and fuel-cycle systems of the future, so that in a couple of decades these systems will be available in the marketplace for deployment.

O Fourth, the advanced technologies to be developed need to embed as many advanced security and non-proliferation features as feasible, so that worldwide expansion of nuclear power can be accomplished in a way that does not threaten our security or the security of the current world order. This technology-development effort needs to be accompanied by an international effort to deploy a non-proliferation regime that is far more robust and extensive than the current regime, administered by the UN's International Atomic Energy Agency in Vienna. The current IAEA regime and its treaty underpinnings have been effective so far, but certainly need bolstering if the regime is to be able to cope with a vastly expanded nuclear-power enterprise worldwide.

O Finally, the development of the deep-geological repository at Yucca Mountain, Nevada must continue to proceed toward an orderly opening date, after having received regulatory approval from the NRC, so that the final disposal of the radioactive waste will no longer be seen as a barrier to continued nuclear-power development.

B. Range of solutions being pursued by Bay Area institutions

Several Bay Area companies/institutions are actively engaged in addressing these five challenges. In fact, although work on these challenges is underway throughout the U.S., Bay Area institutions have important roles in addressing each one of them. Indeed, since the inception of commercial nuclear power in the U.S. nearly five decades ago, Bay Area companies and institutions have been among the leaders, and this continues today.

The following is a brief overview of how various Bay Area companies and institutions support addressing each of the five major challenges discussed above:

<u>First Challenge: operating the existing plants well</u>
PG&E operates a two-reactor station at Diablo Canyon west of in San Luis Obispo, and operates it very well: Diablo Canyon has long been among the leading performers in the U.S. in terms of both safety and economical operation. This performance is supported by a large number of firms in California, many in the Bay Area, who provide engineering services. Many of these firms are small, although a few, such as Bechtel, are very large. Indeed, the Bay Area hosts a major concentration of smaller firms that support all 103 of the country's operating nuclear units, with equipment, analysis, manpower, supplies, and radioactive-waste services. The operating reactors continue to advance technically, employing better control systems, better operator training, better parts-replacement management, and other improvements that often involve very high-tech advances supported by Bay Area firms.

<u>Second Challenge: starting to build new reactors using the "evolutionary" designs</u>
Many of the major technological advances that are incorporated in the new "evolutionary" designs emerged from the Bay Area, including advanced control systems, metallurgical advances, and improved seismic designs. The General Electric Company (located in San Jose for five decades until its recent move to North Carolina) and the Electric Power Research Institute in Palo Alto have for a long time been major forces in this effort. Also, the Lawrence Livermore National Laboratory has supported the US NRC's activities as it performed the technical reviews necessary to certify the new designs and as it has begun the process for approving the newly proposed sites.

<u>Third Challenge: Developing advanced reactor and fuel-cycle systems for the future</u>
The development of advanced design concepts has been, in a major way, the special province of the U.S. Department of Energy, and in the Bay Area that work is concentrated at Lawrence Livermore National Laboratory, collaborating with the Berkeley campus of UC and three other DOE laboratories around the country. Although several advanced concepts are under development around the country, the work here has

centered around a novel advanced reactor concept involving a fast-spectrum lead-bismuth-cooled reactor. The design concept, which is called the SSTAR for "Small Sealed Transportable Autonomous Reactor" (see Figure 1), is small enough that the reactor could be manufactured in a factory and barge-transported to a remote site, where it would run for two decades without the need for refueling. The design has advanced security features, a very safe configuration, and minimal radioactive waste.

Another LLNL effort has involved supporting the DOE initiative to develop advanced fuel-cycle technologies, that would reprocess spent fuel and recycle the useful remaining fuel and some of the more hazardous radionuclides back into specially designed reactors for destruction. The objective of this approach is to substantially decrease the radioactive-waste stream from nuclear power, thereby easing the need for a large number of deep-geological repositories. LLNL has worked on materials problems, advanced fuel technologies, reactor system design, safeguards and security issues, repository technology, and several other high-technology issues.

<u>Fourth Challenge: security and non-proliferation</u>
The issue of security and non-proliferation has been a major concern of several Bay Area institutions for a long time. For decades, faculty at both Stanford and UC-Berkeley have been leading participants in U.S. and international non-proliferation policy development. LLNL has always played a major role in developing advanced technologies that impede proliferation, in developing methods to allow inspectors to detect it is it were to occur, and in supporting broader U.S. non-proliferation policy in many different ways, some of which are classified for national-security reasons. All of these capabilities are still at-work in the same areas, including work on very advanced technologies that can improve overall national security while allowing nuclear power to advance.

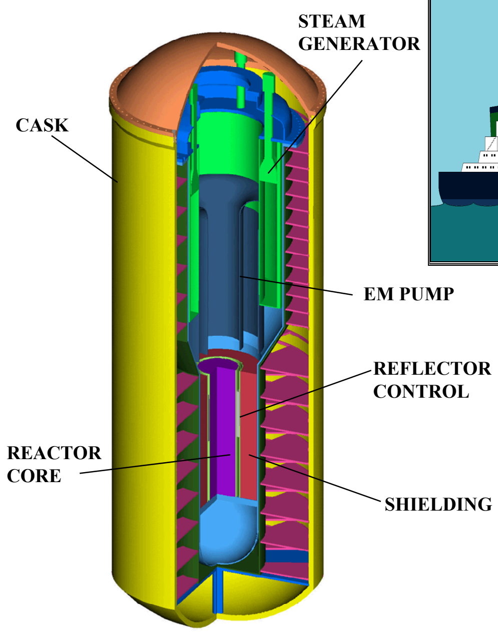
<u>Fifth Challenge: the Yucca Mountain deep-geological repository</u>
The Bechtel Corporation (San Francisco) has an important role as the prime contractor working in Nevada to develop the repository. Both Lawrence Livermore National Laboratory and Lawrence Berkeley National Laboratory have been major contributors for more than two decades in developing the underlying scientific knowledge needed to design the Yucca Mountain repository and to assure that it will meet all applicable safety regulations. Among LLNL's long-standing roles has been developing the methods to enable the project to analyze the underground environment. LNL has also been performing tests to understand water flow and radionuclide transport, studying the potential for corrosion of the canisters that will contain the waste underground, helping to understand how the waste can be transported from elsewhere in the U.S. to the repository safely and securely, and developing advanced materials. One of LBNL's major roles has been in understanding flow and transport in the underground environment, and assuring that this understanding can be translated into acceptable design solutions for the engineered system. Both LLNL and LBNL are expected to continue providing strong technical support to the repository program as it progresses into the future.

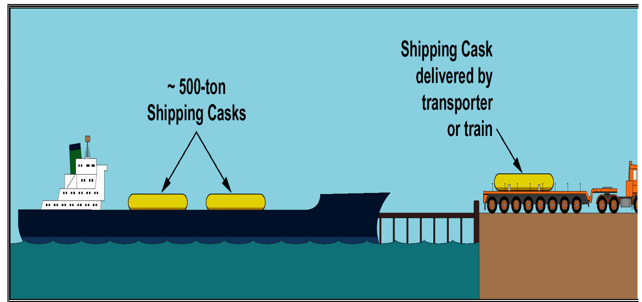
C. Summary of what might be different in 5 years

It is clear that for many decades a number of Bay Area institutions have played major roles both domestically and internationally in the nuclear-power enterprise. This is very likely to continue into the future. What is likely to be different in a few years is that a number of new commercial nuclear-plant construction projects will have begun around the country, supported as in the past by a wide array of high-technology work at our local institutions. Another aspect that is likely to be different is that the U.S. Department of Energy is embarking on a major new advanced-reactor-system development effort, a multi-year program to develop the advanced technologies mentioned above. Again, several institutions in the Bay Area are very likely to play major roles in that program. Still a third aspect that might be different in a few years is that important discussions are underway about modifying and enhancing the international treaty regime, administered by the UN's International Atomic Energy Agency in Vienna, that assures that nuclear-weapon proliferation concerns are addressed around the world. Several Bay Area experts and institutions will likely play major roles in the policy analyses and deliberations that will support the national and international political debates about enhancing the current regime, just as they have in the past in supporting the existing regime.

Last but not least, several Bay Area institutions have had major long-standing roles in educating the next generation of scientists, engineers, and others whose work supports the whole enterprise. As nuclear power expands, this educational role will continue and indeed will surely expand.

The <u>S</u>mall <u>S</u>ealed <u>T</u>ransportable <u>A</u>utonomous <u>R</u>eactor (SSTAR)





Some SSTAR Attributes

- **Small:** Small (10-100MWe) and modular to allow factory assembly and transportation
- **Secure:** proliferation resistance through sealed or cartridge core and supplier nation controls
- **Transportable:** enables factory manufacturing and avoids need for complex infrastructures
- **Autonomous:** automatic load level
- **Passive intrinsic safety** features reduce need for operator actions
- **Simplified design** to reduce maintenance and operational needs
- **Energy products** include electricity, fresh water, hydrogen, industrial and space heat

<u>Figure 1</u>

The SSTAR reactor concept under development at Lawrence Livermore National Laboratory, in collaboration with UC-Berkeley and three other large DOE laboratories, supported by the U.S. Department of Energy.